Surge Suppression in a Typical Home Wiring System

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Significance:
Part 3 – Recorded occurrences
Part 7 – Mitigation techniques

The present interest in this report is historical as the experiments and devices it describes represent the initial efforts in addressing the emerging problems associated with the introduction of semiconductors in the consumer market.

This (now declassified) proprietary report was prepared to document experiments performed in the early sixties to assess the capability of devices available at that time for serving as surge-protective devices in residential circuits. The context was that the emerging electronic appliances were found vulnerable to transient overvoltages and therefore in need of some form of protection.

The technology at that time offered the well-proven selenium rectifier (under the General Electric trade name “Thyrector” among other similar offerings in the market), the well-known low-pass RC filter, and the emerging five-layer semiconductors. All these were then valid candidates but of course became completely supplanted ten years later when zinc-oxide based varistors were stumbled upon and quickly recognized as a promising technology.

Interesting observations on the occurrence and propagation of surges in a low-voltage ac power system are also documented in this report, and these are still applicable today.

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SUMMARY

Artificial surges approximating typical switching surges were injected in a home wiring system. Various types of surge suppressors were connected to various points of the system and their effectiveness evaluated.

For the short (3 µs) surges applied, the following surge suppressors provided the attenuation tabulated below, showing the effectiveness of the AC switch and SSS switch

SUPPRESSOR	% of original surge at location of suppressor	% of original surge at other points
2" Thyrector	50	50
4" Thyrector	50	50
RC	66	66
GE "AC Switch"	10	30
Hunt "SSS Switch"	10	30
Controlled Avalanche Diode	30	90

Further work is required to investigate the Thyrector performance with surges of longer duration

KEY WORDS

INFORMATION PREPARED FOR Transient Overvoltages Pooled Program

TESTS MADE BY S. Deiber - F. D. Martzloff

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COMPONENT Converter Circuits Engineering

APPROVED R. G. Hoft RG Hoft 7/8/63

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SUPPLEMENT TO TIS 63GL97

Surge Suppression in a Typical Home Wiring System

August 2, 1963

SUMMARY

The surge suppression data for the selenium Thyrector devices originally reported in TIS 63GL97, dated 6/24/64 were based on a 10 cell/250 ACV unit applied to the 125 ACV circuit. The appropriate unit should have been a 5 cell/125 ACV model, which is the proper rating for the test conditions. The surge suppression provided by this unit is a significant improvement over the values previously reported. This summary supersedes the summary in the original report.

A comparison test was made in a laboratory model of a home wiring system, using both 10 and 5 cell Thyrectors as well as a 5 layer switch and the RC network.

Results of both tests are summarized below. These measurements are taken at the end of a line with the suppressor at central fuse box and surge applied on a second line end.

<table>
<tr><th rowspan="3">SUPPRESSOR</th><th colspan="3">% of Original Surge at Line End</th></tr>
<tr><th rowspan="2">Typical Home Test</th><th colspan="2">Laboratory Model Test</th></tr>
<tr><th>Device Rated 250 Volts</th><th>Device Rated 125 Volts</th></tr>
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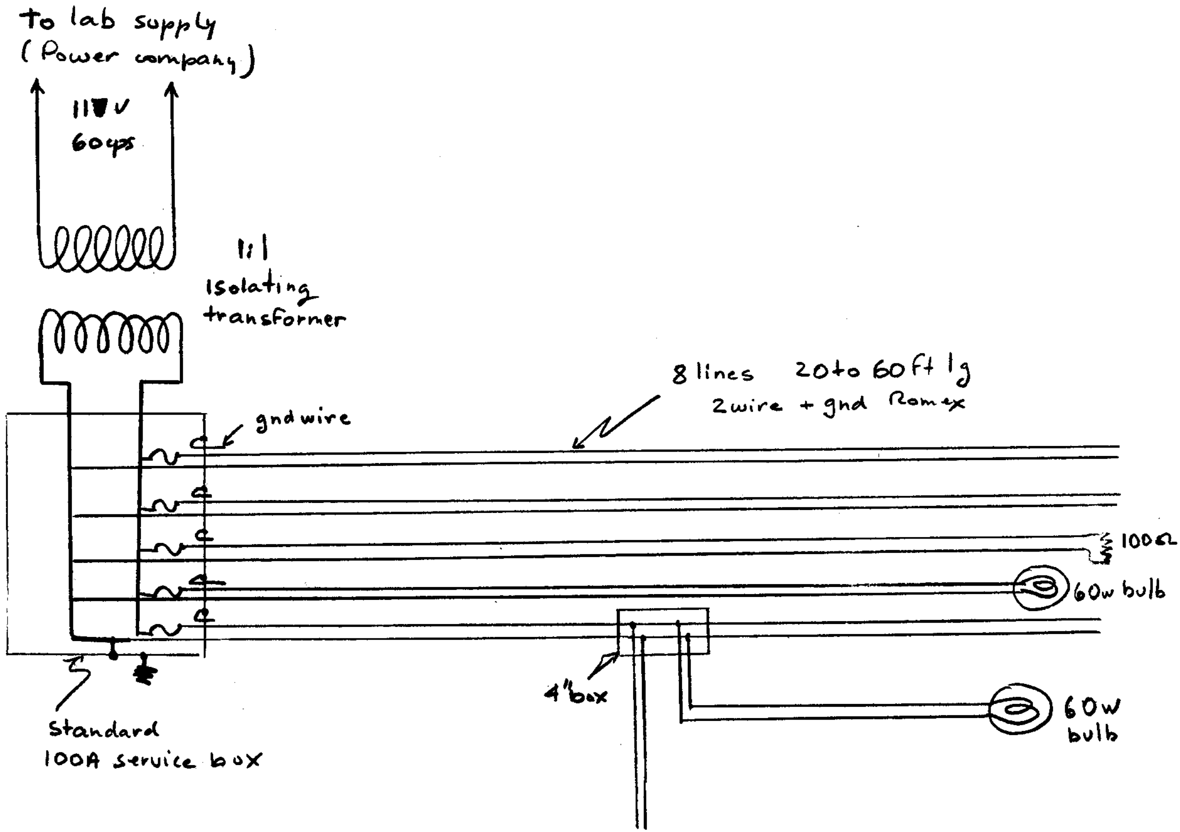
<tr><td>2" Thyrector</td><td>50 (with 10 cell)</td><td>50 (with 10 cell)</td><td>30 (with 5 cell)</td></tr>
<tr><td>GE "AC Switch"</td><td>30</td><td colspan="2">28</td></tr>
<tr><td>RC</td><td>66</td><td colspan="2">66</td></tr>
</table>

I. INTRODUCTION

The purpose of this test is to repeat, in the laboratory model of a house wiring system, the work reported in TIS 63GL97 and to evaluate the effectiveness of proposed transient overvoltage suppressors. In the original report, the Thyrectors evaluated were 250 volt models (6RS21SA10D10, etc.). During the test program, the suppression devices were always located in the 120 volt circuit so the evaluation was repeated in the laboratory using the proper 120 volt Thyrector (6RS21SA5D5, etc.), the GE 5 layer AC switch, and the RC network. Surges were injected in the wiring system of the house and measurements recorded at an outlet with the suppression device located at the central fuse box.

This new study reflects the proper comparison of the effectiveness of the various devices studied and this additional data indicates that the 1" Thyrector (6RS21SA5D5) should be considered for household transient protection as well as the 2" Thyrector (6RS25SA5D5). This new look brings the 1" Thyrector price to about $1.00 and the 2" Thyrector to $3.50 which makes the Thyrector competitive valuewise.



"Laboratory model"

II. TEST CONDITIONS

The tests were made on a laboratory model of a house wiring system consisting of one standard service fuse box feeding 8 lines of Romex cable and 3 branch lines from one line, with length varying from 20 to 50 feet. The cable is strung in the room away from the ground in some locations and is close to the ground in some others. Light bulbs are connected at some line ends while others are left open. Single phase 117 volt 60 cps power is applied to the service box from the low impedance laboratory supply through an isolating transformer.

Initial tests have shown that the portable surge generator used in the "typical house" can induce the same level and wave shape surges in this laboratory model which indicates that a reasonable degree of approximation has been obtained.

This was confirmed further by the similarity of the test results for the same devices between the "typical home" and the laboratory model.

All tests were made with the surge applied at one line end, the suppressor installed with 6" leads at the fuse box, and the resultant surge at one other line end measured with a Tektronix 551 oscilloscope (this provides linear time base compared with the logarithmic time base of the automatic oscilloscopes used in the "typical home" test.

The laboratory model was built for further work in this program and will continue to be available.

III. TEST RESULTS

The two attached oscillogram sheets show a composite recording for 5 cell and 10 cell Thyrector units, both 1" and 2" Thyrectors as well as the original surge and they indicate the improved surge attenuation provided by the 5 cell unit.

The GE five-layer switch limits the voltage peak by abruptly turning on and with a subsequent low voltage, reducing the total surge energy delivered to equipments connected to the wiring system.

IV. SUMMARY AND CONCLUSIONS

Three types of surge suppressors, Thyrectors, RC's and five-layer switche were investigated under conditions approximating typical switching surges generated within the home, which is the most frequent type of transient over-voltage in a house wiring system.

The crest of the surges was in the range of 1500 to 2000 volts with a duration in the order of 3 microseconds.

The resultant attenuation is tabulated below:

SUPPRESSOR	% of Original Surge at Line End		
	Typical Home Test	Laboratory Model Test	
		Device Rated 250 Volts	Device Rated 125 Volts
1" Thyrector	No Test	70 (with 10 cell)	42 (with 5 cell)
2" Thyrector	50 (with 10 cell)	50 (with 10 cell)	30 (with 5 cell)
GE "AC Switch"	30	28	
RC	66	66	

In terms of attenuation per dollar, the RC has the lowest cost, and the five-layer switch and the Thyrector have comparable costs. The limitations are most severe for the RC whose effectiveness is dependent upon circuit parameters and cannot attenuate long surges. The Thyrector effectiveness in the initial period is determined by its junction capacitance and it has proven capability to absorb the energy of longer surges. A combination of Thyrector with RC can increase the initial effectiveness.

The five layer switch requires additional circuitry for DC applications and therefore is primarily attractive for AC circuits when loss of 60 cps power for a half cycle is not objectionable. It is the most effective and most promising surge suppressor in the present state of the art.

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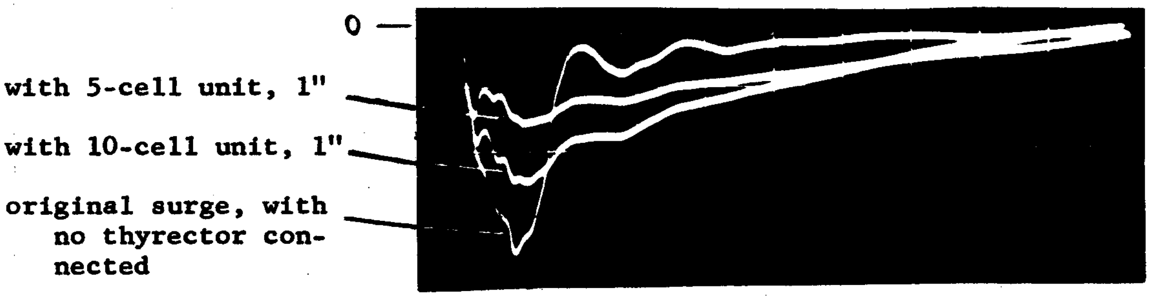
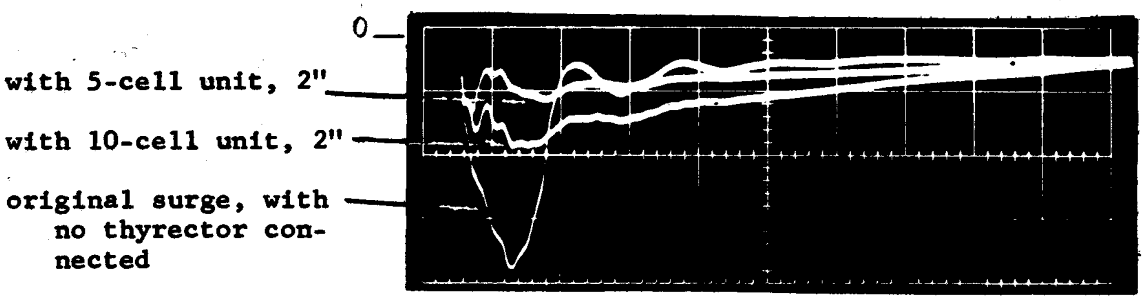
Surge Suppression Measurement

in the Laboratory "house wiring system"

Comparison between performance of 5-cell thyrectors and 10-cell thyrectors, 1" and 2".

Surge applied to one line end, propagating to central fuse box where the Thyrector is connected, and measured at one other line end.





Both oscillograms: 500 volts/division

1 μs/division sweep

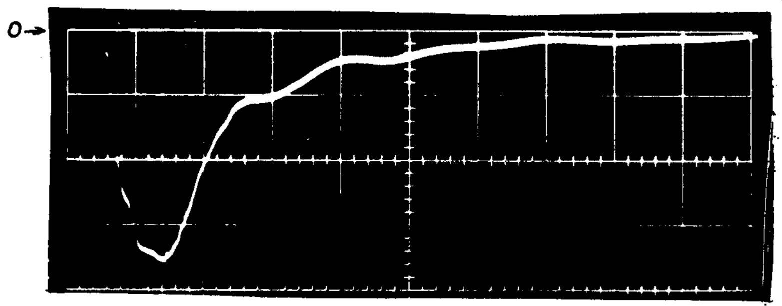
Surge Suppression Measurement

in the Laboratory "house wiring system"

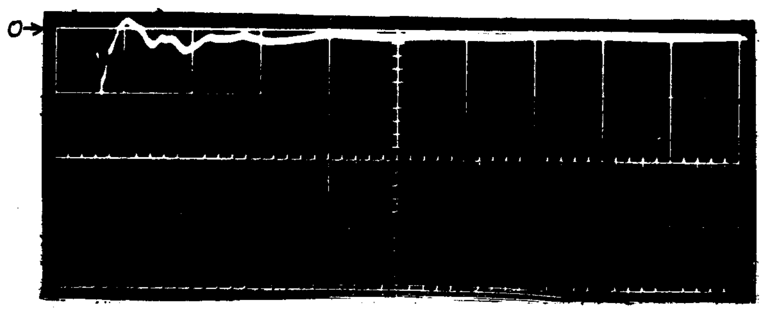
Surge suppression with RC and with 5 layer switch.

Surge applied to one line end, propagating to central fuse box where suppressor is connected, and measured at one other line end.

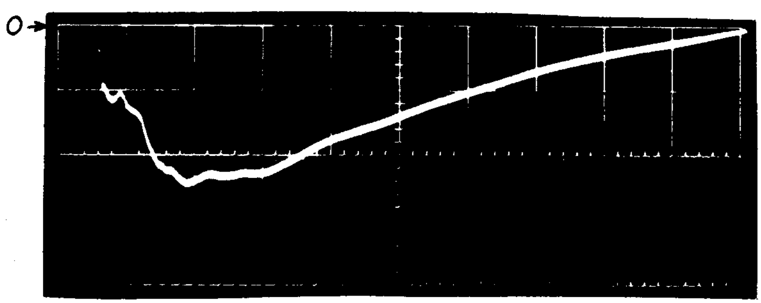
original surge, with no suppressor connected



with GE 5 layer AC switch and 1 ohm resistor



with 0.05 μF capacitor and 10 ohm resistor in series



All oscillograms: 500 volts/division

1 μs/division sweep

I Introduction

The purpose of the tests reported here was to evaluate the effectiveness of proposed transient overvoltage suppressors under conditions approaching those observed in actual field measurements.

The experiments were based on previous measurements in order to insure that the test conditions were representative of actual conditions, and also would not endanger the equipment of third persons; i.e. that of neighbors or the power company.

Surges were injected in the wiring system of a house and measurement of the surges at various points of the house were made with the proposed suppressor connected at a central (fuse box) location or at a single outlet.

Although the conclusions apply directly only to a particular house wiring system, worthwhile inferences can be drawn for other applications.

II Test Conditions

A. General Considerations

Previous measurements and observations made during earlier parts of this program and reported under TIS 62GL191 allow to make a reasonable approximation of typical switching surges occurring in a house wiring system. Examples of these are also shown in Figures 4 and 5 at the end of this report.

Because of the difficulty encountered in making transient current measurement in "non-laboratory" conditions, it is nearly impossible to evaluate directly the energy involved in voltage surges. Further work is required in this area.

More specifically, the following facts are known, and allow some conclusions to be drawn:

1. Transients overvoltages in the 1500 volts range which occur "naturally" (i.e., not deliberately created for these tests) in a specific house (J. H. Ross, Schenectady) could not be detected at a significant level (over 400 volts) in the adjacent house (F. D. Martzloff, Schenectady). Thus we have an indication that the attenuation through the meter coils, service entrance and division of the traveling wave at the service pole is sufficient to make harmless to neighbors the surges which would be deliberately injected in a test house.

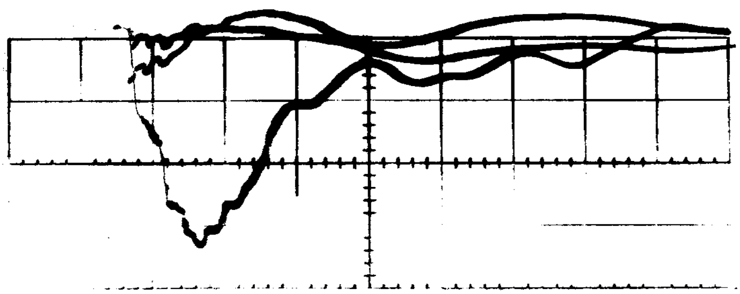
2. Field measurements have shown that surges due to switching of loads within a house is the most frequent source of damaging transient overvoltages in a house wiring system; protection against these (and eventually only these) would therefore decrease by several orders of magnitude the possible frequency of damaged semiconductor equipments.

3. Several instances were found where voltage crests were in the 1500-2000 volt range, with the duration of the major loop of the oscillation about 1 to 4 microsecond. Thus, a "typical" surge wave form should approximate these values.

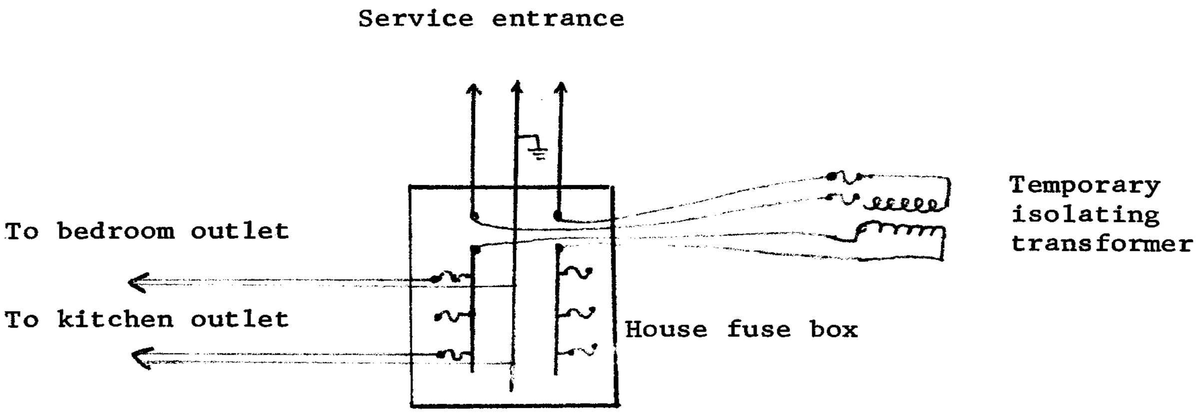
4. Surge impedance of a house wiring cable was found to be in the 10 to 100 ohm range. Thus, for short pulses, currents as high as $\frac{2000}{10} = 200$ amperes may easily be involved.

B. Test Procedure

Therefore, based on the above facts, a series of tests were made at the residence of R. G. Hoft in Schenectady, where surge propagation measurements had been made in 1962.



Voltage applied to one phase of house wiring (large pulse) and surge passing through isolating transformer into both phases of service entrance.
(500 volts/division, 1 us/division linear sweep)



Circuit diagram showing surge injection into house and attenuation of surge for service entrance.

FIGURE 1

The portable surge generator previously used in this work was used again. With additional capacitance added to the charging capacitor, it is capable of delivering single shot surges of 1500 volts crest and 3 microseconds duration into the house wiring system.

A temporary isolating transformer was inserted between the service entrance and the house fuse box in order to attenuate the surge sent into the service entrance, to provide further protection against surging adjacent houses.

Figure 1 shows the connections at the fuse box and oscillograms of the surge applied within the house compared to the surges transmitted to the service entrance.

Automatic recording oscilloscopes (those used for the field measurement of transient overvoltages) were used to make simultaneous recording of the surge at the sending and receiving end, and eventually at an intermediate point.

During the measurements, incadescent lamp loads were turned on, but other appliances were disconnected. Each branch circuit was generally loaded with one or more 60 watt bulb; open end conditions existed at most wall recptacles, with the resulting reflection and voltage doubling effects.

Two test series were conducted; one with the surge injected at the fuse box and a proposed suppressor connected at a single outlet, presumed to protect whatever device may be connected at that outlet; the other test series was made with the surge injected at one outlet, and propagating to the fuse box where it met a proposed central suppressor installed there; from there the surge, or what was left of it, propagated through the rest of the branch circuits, and was measured at the same outlet as in the first series.

III Proposed Suppressors

The devices investigated in this test series were the following:

- 1" Thyrector cell, cat 6RS21SA10D10 rated 200 volts steady state
- 2" Thyrector cell, cat 6RS25SA10D10 rated 200 volts steady state
- 4" Thyrector cell, cat CRS15SA10D10 rated 200 volts steady state
- RC made of a 0.05 μF 1000 volt paper capacitor and 10 ohm 1 watt carbon resistor in series
- General Electric AC switch (5 layer switch) in series with a current-limiting resistor
- Hunt SSS switch (5 layer switch) in series with a current-limiting resistor
- General Electric controlled-avalanche rectifiers (back-to-back)

The Thyrector transient voltage suppressor has been available for some time, but its response for fast and short transients is not well defined. For very fast transients, it is expected that the junction acts as a capacitor. Prices range from $2.00 for the 1" cell to $24.00 for the 4" cell in quantities above 1,000.

An RC network is, of course, an obvious surge suppressor within the limits of its time constant. The values selected here were deliberately just short of the pulse duration in order to check the marginal case. Price of the two components is about $ 0.40 above 1,000 pieces.

The five-layer switch is a relatively new solid state device[1] which has the property of turning on, regardless of the polarity, when the voltage across its terminals exceeds a predetermined level. In the "off" state it presents a very high impedance right up to the turn-on voltage, contrary to the Thyrector which has a definite maximum steady state voltage rating determined by the leakage current.

The turn-on characteristics of the two five-layer units in this investigation have been measured and are included as Appendix I. It is significant that the characteristic is far more "flat" than other devices such as gaps or arresters; the curves published in the final report of the 1962 program are also reproduced for reference in the appendix, together with the turn-on time of the five-layer switches.

One unit was a Hunt SSS switch available from Hunt Electronics, Andjon Ave., Dallas, Texas. Its steady state rating is 8 amperes RMS. In lieu of specific surge data, it was decided to limit the half-cycle surge current to 80 amperes peak, so that a 2 ohm resistor was placed in series to limit the 60 cps current following turn-on. Estimated price is $2.00 in quantities to selected customers.

Another unit was an engineering sample of the General Electric AC switch developed by the Rectifier Component Department. It is rated 25 amperes RMS with a ½ cycle rating estimated by ATL at 200 amperes, so that a 1 ohm limiting resistor was connected in series. No price information is yet available for this unit.

The controlled avalanche rectifier can also be used to a certain extent as a surge protector, although the purpose of connecting two diodes across the line in this test series was to compare the performance of a 7 AD diode to that of the diode tested in 1962 for surge characteristics, both of which have fairly comparable mass and physical configuration.

IV Test Results

A. First Series - Suppressor at Outlet

The surge was applied between ground and one line at the fuse box, and the proposed suppressor installed at an outlet in the kitchen connected to the same line. Voltages were measured at both locations, the corresponding oscillograms are shown in Figure 2 for the various

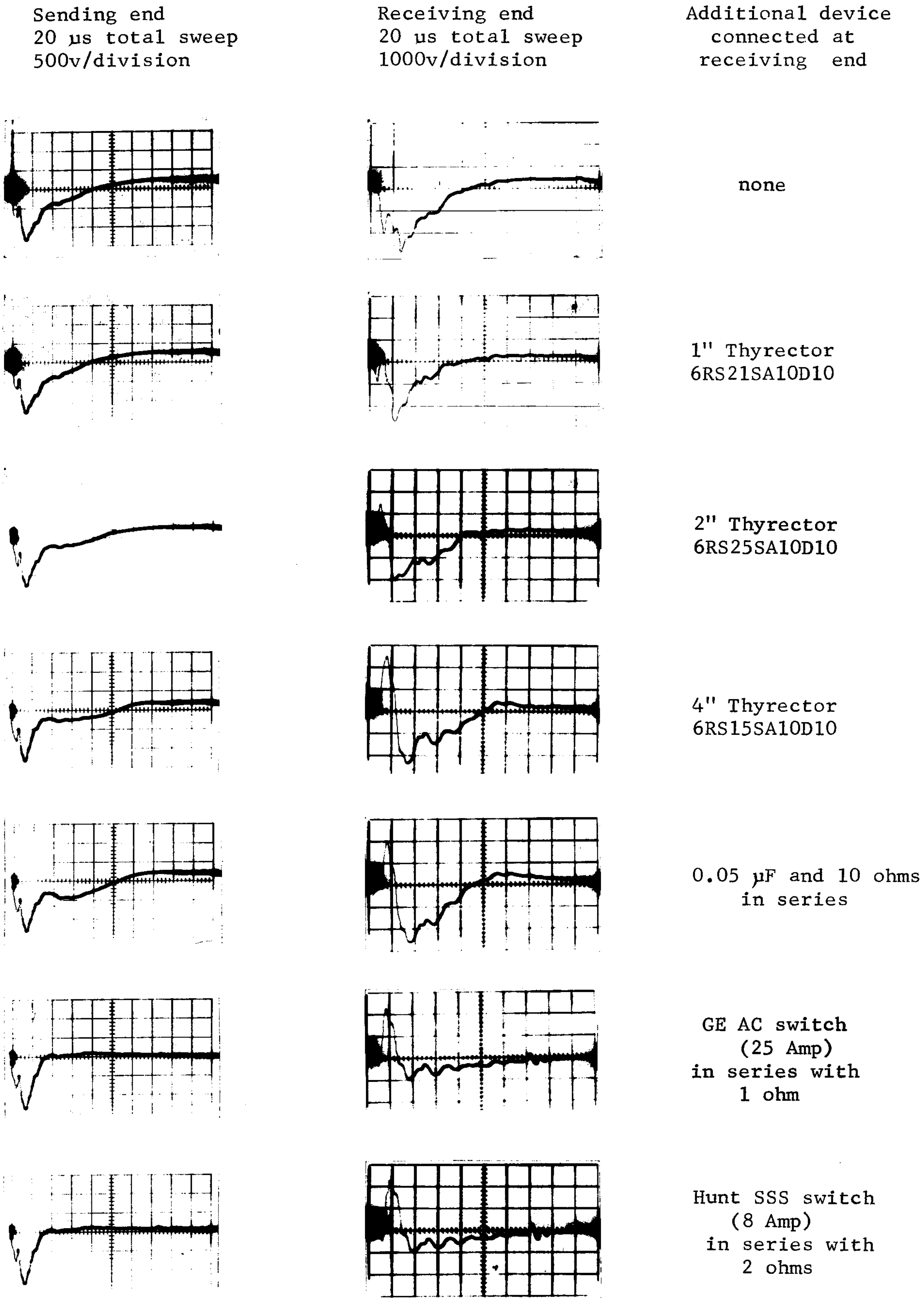


FIGURE 2

Surge applied at fuse box, received at kitchen outlet types of suppressors. The following observations may be made concerning the oscillograms:

a - No Suppressor

The voltage crest at the receiving end is approximately the double of the voltage crest injected at the fuse box, corresponding to the open transmission line condition; this is the extreme of the case where there would be only a light load connected to the outlet to absorb any of the surge energy.

b - 1" Thyrector Cell

The front of the wave is affected, but the crest level is not significantly decreased; after the second division of the time scale (2 μs), the surge is reduced to about 60% of the value without suppressor. No further tests were made with this size cell since the effect on the surge was so small.

c - 2" Thyrector Cell

The negative crest is reduced to about 70% of the initial value, but a positive peak appears, due to the effect of loading the "transmission line" (Romex cable) with the capacitance of the Thyrector cell.

d - 4" Thyrector Cell

The same effects observed for the 2" cell are also apparent here, with a greater initial positive crest as the capacitance of this cell is larger.

3 - RC Network

The striking fact here is the similarity of the wave shape with that of the 4" Thyrector cell, justifying the hypothesis that the initial behavior of the Thyrector is similar to that of a capacitor.

f - Five-layer Switches - Both GE and Hunt

The positive crest which has appeared previously at receiving end

Sending end
100 μs total sweep
1000v/division

Fusebox
100 μs total sweep
500v/division

Kitchen outlet
100 μs total sweep
1000v/division

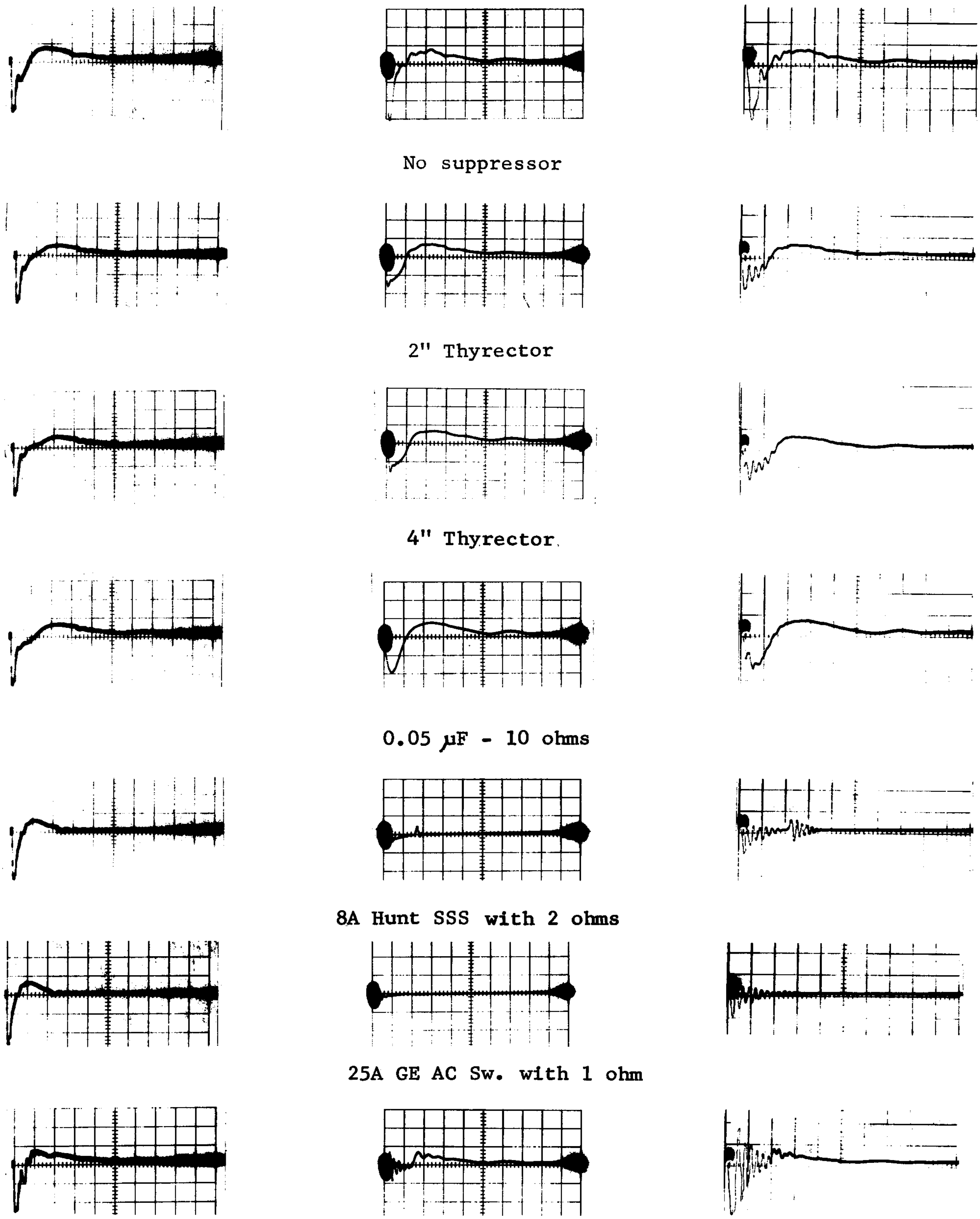


FIGURE 3 Surge applied to bedroom outlet, received at kitchen outlet, with suppressor installed at fuse box

is not removed by the expected action of the switch, while the negative portion of the wave is limited to a substantially lower level. Thus, the significance of the initial positive crest is not quite clear. Because of the limitations of time, these readings could not be repeated. However, when compared to the next series, they give an additional indication of the performance of the suppressor. It is also apparent that the clamping effect of the switch is felt at the sending end after 3 microseconds.

B. Second Series - Suppressor at Fuse Box

The surge was applied at a bedroom outlet, between the ground side of the outlet and the other line at 115 volts. From these, the surge was transmitted to the fuse box, where a proposed suppressor was connected between the box ground and the same 115 volt line. From the fuse box, the residual surge resulting from division into the branch circuits and their action of the suppressor was transmitted through the house, and among other points to the same kitchen outlet used in the first series, where the incident surge, without any other suppressor, was measured. Voltage at the sending point as well as at the fuse box, directly across the suppressor, were also measured. The corresponding oscillograms are shown in Figure 3, and the following observations can be made:

a - No Suppressor

The surge applied at the bedroom outlet at 2500 volt crest appears only with a 1500 volt crest at the fuse box, as a result of the attenuation of the cable between the point of application to the fuse box as well as the division between the branches at the fuse box.

The surge leaving from the box and traveling towards the kitchen outlet appears there with a 2800 volt crest again as a result of the refelection at the high impedence line terminal.

b - Thyrector Cells (2" and 4")

The initial negative crest at the sending end is not appreciably affected by the presence of the Thyrector at the fuse box; the following positive oscillation however is reduced.

At the fuse box, the negative crest is reduced to half the value without the suppressor, and the positive oscillation is slightly reduced.

The resulting surge at the kitchen outlet is also reduced to about half the original crest value, with some oscillations or reflections.

c - RC

There again the similarity between the effect of the Thyrector and the RC is apparent. The reduction for the small value of RD is slightly less than for the Thyrector, but the wave shapes are quite similar, suggesting that for short transients, the Thyrector is effective inasmuch as the junction capacitance acts as an RD. It would be desirable to measure this capacitance; this will be attempted.

d - Five-layer Switches - GE and Hunt

For both switches, the initial negative crest at the sending end is not affected; the positive oscillation occurs sooner, as the clamping effect of the switch is transmitted back to the sending end; the clamping effect is then complete after 2.2 divisions of the oscillogram (3 us).

At the fuse box the clamping effect of the switch is such that the initial crest is lost within the beam halo, at less that 600 volts. The Hunt unit seems to take a slightly longer time - or higher voltage - to turn on, as indicated by the slope of the trace as it leaves the halo, and the short positive pulse at the probable polarity reversal of the surge.

The voltage at the kitchen outlet shows the resulting low amplitude oscillations or reflections for the surge existing at the fuse box.

e - Controlled Avalanche Rectifiers

Two diodes connected back-to-back were also used as a possible suppressor, as a side effect of another test discussed later. The avalanche effect of the rectifier effectively limited the crest of the voltage surge at the fuse box, the maximum crest value for this 400 volt rated diode did not exceed 800 volts.

f - Controlled Avalanche versus Conventional Rectifiers

Attempts were made to correlate the test results of the 1N679 diode investigation made in 1962 with the results under the simulated switching surge of this test series. The 1962 tests used a .1 x 5 us wave shape while the present simulated surge had an approximate wave shape of .2 x 2 us wave shape.

The 1N679 diode (2 samples) survived a 2000 volt crest, while it failed at 3000 volts (average failure level for similar conditions under .1 x 5 us wave were 1500 volts). The difference is attributed to the shorter impulse duration.

On the other hand, the 7 AD controlled avalanche rectifier (sub-miniature size) which proved an effective suppressor for the surge up to the 2000 volt level, also failed (by short circuit) for the energy level corresponding to the 3000 volt crest surge which was also fatal for the 1N679. Here again, because of time limitations in the non-laboratory conditions, the test was not refined further.

V Discussion of the Results

The three types of suppressors investigated in this test series represent radically different approaches to surge protection, and thus their effectiveness and limitations, as well as cost, are widely different. The Thyrector has proven adequate capability of energy absorption; however, for fast transients, its action is limited to that of the equivalent junction capacitance, which is not to say that it is ineffective. The Thyrector will then have the same limitations as an RC for fast transient while of course having a higher price. On the other hand, for longer transients, when the RC becomes ineffective to absorb the energy, the Thyrector can dissipate it.

When fast transients are involved both the RC and the Thyrector act as capacitance dividers. Their effectiveness in limiting voltage transients thus depends on the load circuit parameters and will vary depending on the load conditions. This makes them questionable as universal surge protectors to be merely plugged in any circuit. For specific applications when the load is well defined, this objection does not apply.

Now, the five-layer devices operate as voltage sensitive switches. As long as there is enough current (milliamperes) available to turn them on, their clamping effect is independent from other cirucit parameters. Their action is also the fastest (200 to 500 nanoseconds) and the voltage they allow to pass the lowest. The junction capacitance of these devices is not known at this time; if anything, it contributes further to the surge suppression.

When applied on an AC line (obviously they could not be used in a DC circuit without forced commutation or other circuit complexity), the 60 cps power supply will be shorted from the moment of application of the surge to the next zero of the sine wave. This may or may not be an objection. Of course, a current-limiting resistor will be needed in series with the switch if the impedance of the AC supply is too low for the short-circuit current to remain below the ½ cycle surge rating of the switch. The cost of the device is not yet very firm. There is a strong possibility that if other applications justify large production quantities, or if the use as an effective surge suppressor can become popular, the price may be lower than that of Thyrectors.

VI Summary and Conclusions

Three types of surge suppressors, Thyrector, RC's and five-layer switches, were investigated under conditions approximating typical switching surges generated within the home, which is the most frequent type of transient overvoltage in a house witing system (Figure 4 and 5).

The crest of the surges was in the range of 1500 to 2000 volts with a duration in the order of 3 microseconds.

The resultant attenuation is tabulated below.

SUPPRESSOR	% of original surge at location of suppressor	% of original surge at other points
2" Thyrector	50	50
4" Thyrector	50	50
RC	66	66
GE "AC Switch"	10	30
Hunt "SSS Switch"	10	30
Controlled Avalanche Diode	30	90

In terms of attenuation per dollar, the RC is the lowest cost, then the five-layer switch and last the Thyrector. The limitations are most severe for the RC whose effectiveness is dependent upon the circuit parameters anc cannot attenuate long surges. The Thyrector effectiveness is limited in the initial period by the circuit parameters, and in order to have sufficient junction capacitance, an extremely large (and expensive) cell may be required. A combination of Thyrector with RC is more appropriate.

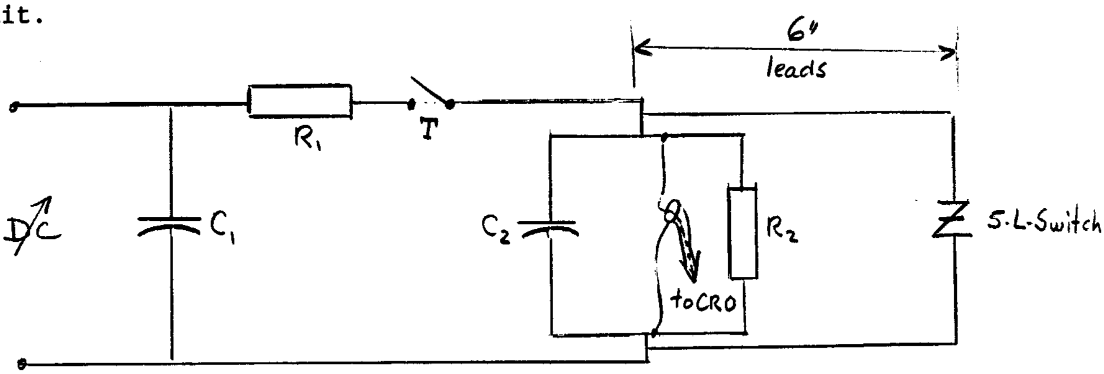
The five-layer switch, primarily attractive for AC circuits is the most effective and the most promising universal surge suppressor which has been found in the present state of the art.

APPENDIX I

Turn-on Characteristics of Five-layer Switches

Test Circuit

A capacitor C_1 is charged at an adjustable voltage. It is discharged into a capacitor C_2 through resistor R_1 when the thyratron T fires. The test piece, with or without additional parallel resistance is in parallel with C_2. The rate of voltage rise is controlled by R_1C_2' while the rate of decay is controlled by $R_2'C_1$ where R_2' and C_2' are the equivalent values of all the resistance and capacitance across the terminals of the test circuit.



The values used for the data shown below are the following:

R_1 = 25 ohms, non inductive

R_2 = 750 ohms, non inductive

C_1 = 0.01 μF 15 KV oil filled

C_2 = 0.001 μF 15 KV oil filled

Resulting in a .1 x 5 μs double exponential wave where where R_1 and C_2 shape the tail of the wave

The wave shapes of the applied voltage and of the voltage measured with the five-layer switch connected across C_2 are plotted on the following page, from the oscilloscope readings.

TABLE I

Turn-on Characteristic of Five Layer Switches
With .1 x 5 μs Voltage Wave

Original Crest Volts	Hunt Unit V_R Crest Volts	Hunt Unit t_1 μs	Hunt Unit t_2 μs	GE Unit V_R Crest Volts	GE Unit t_1 μs	GE Unit t_2 μs
600	250	.5	.1	220	.5	.1
800	300	.5	.1	220	.5	.1
1000	350	.5	.1	225	.5	.1
1500	420	.5	.1	250	.5	.1
2000	500	.5	.1	300	.5	.1
3000	750	.5	.1	350	.5	.1
4000	1000	.5	.1	400	.5	.1
DC turn-on	235			220		

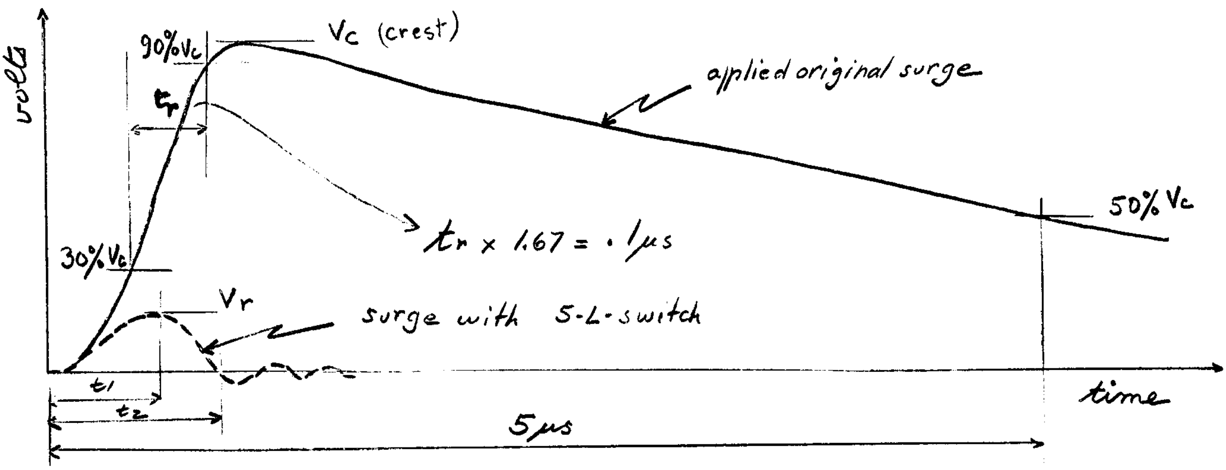
NOTES- 1 The GE unit shows a lower increase in the voltage V_R as the original crest voltage is increased.

This may be due to a lower resistance across the turned on switch or to a longer function capacitance (7½ x 7½ mm for the GE unit and 3 x 3 mm for the Hunt unit). Part of the voltage V_R is also due to inductive drop in the 6" leads used to simulate a practical connection to the protected circuit.

2 An increase of one decade in the values of C_1 and a decrease of one decade in the value of R_2, resulting in the same wave shape with 10 times the energy flowing across the switch did

NOTES (continued)

not produce significant change in the time to turn on. The voltage V_R was increased by about 20 to 30%, as a result of the increased $IR + L\frac{di}{dt}$ increase across the switch and leads.

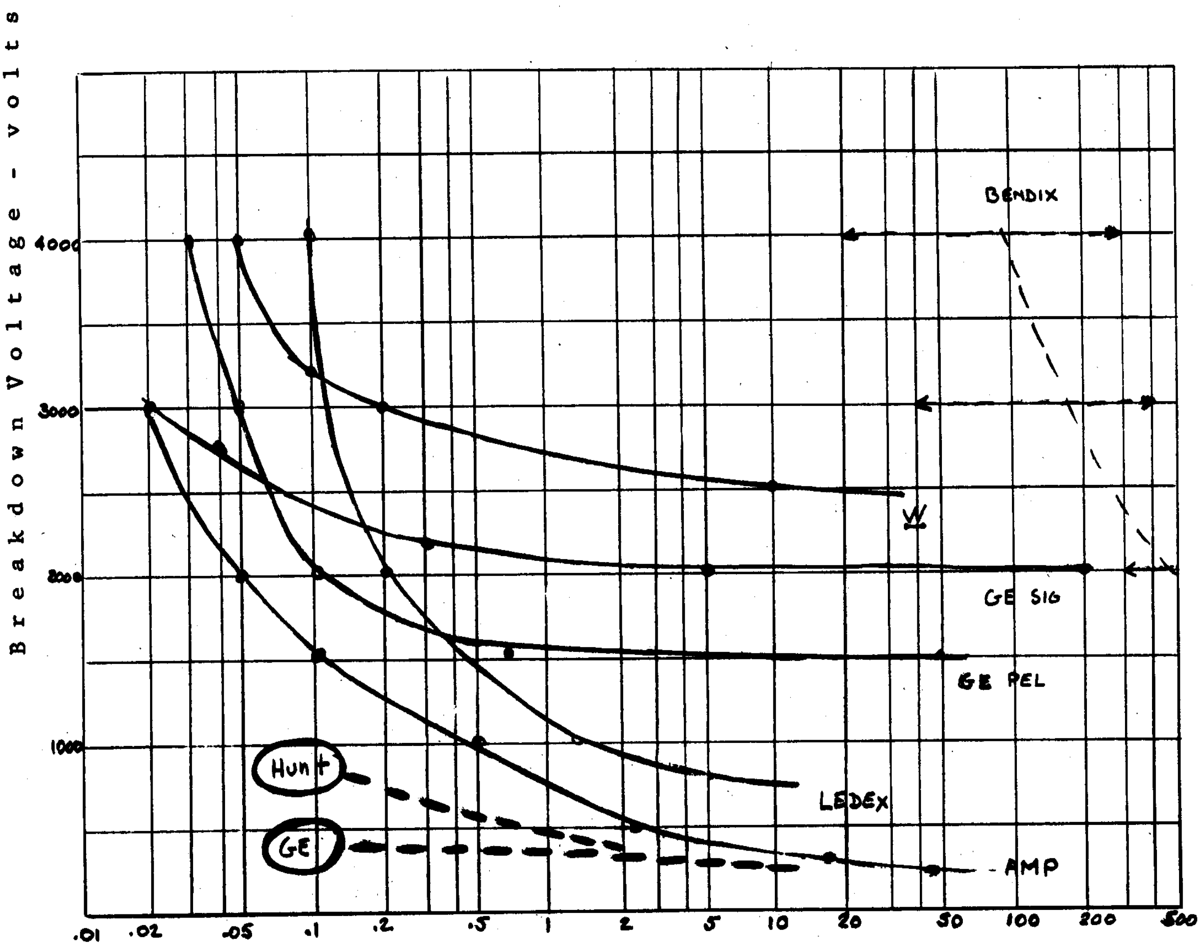


In order to apply increasing surge voltages, the DC voltage of the charging circuit was raised step by step, resulting in the crest volts values shown in Table I without the five-layer switch across C_2. The Hunt unit and the GE unit were successively connected across C_2 with 6" leads simulating a practical connection to a circuit to be protected and the crest V_R across the protected circuit read as well as the times t_1 and t_2, which are tabulated in Table I.

Conclusion

The voltage clamping action of these devices is considerably faster than any other surge suppressor, and the time to clamp practically constant. The crest of the voltage allowed to pass does, however, increase with the crest of the initial surge; this corresponds to a simultaneous increase of the rate of voltage rise since the time to crest is held constant, as well as an increased current through the device and the leads.

Compared to other voltage sensitive devices, such as the gaps or arresters measured in 1962[2], or a Thyrector under the same conditions, the surge suppression is considerably greater.



1963 Data: Hunt & GE 5 layer switches - equivalent time-lag characteristic

1962 Data: <u>Gap Description</u>

BENDIX	-	Cat. TG98 Rated 375 volts
<u>W</u>	-	Style 632A189A01 Rated 175 volts max.
GE Sig	-	Signal arrester Cat. 9LA4C4
GE Pel	-	Secondary arrester Model 9L15CCB001 rated 175 volts max.
LEDEX	-	Transient Control Part No. A-46800-001 rated 200 volts
AMPEREX	-	Cat. 4369

Points shown are average values of several single shot, except Bendix which was extremely erratic.

Time-lag Characteristics of Various Gaps - 0.1 μs rise

REFERENCES

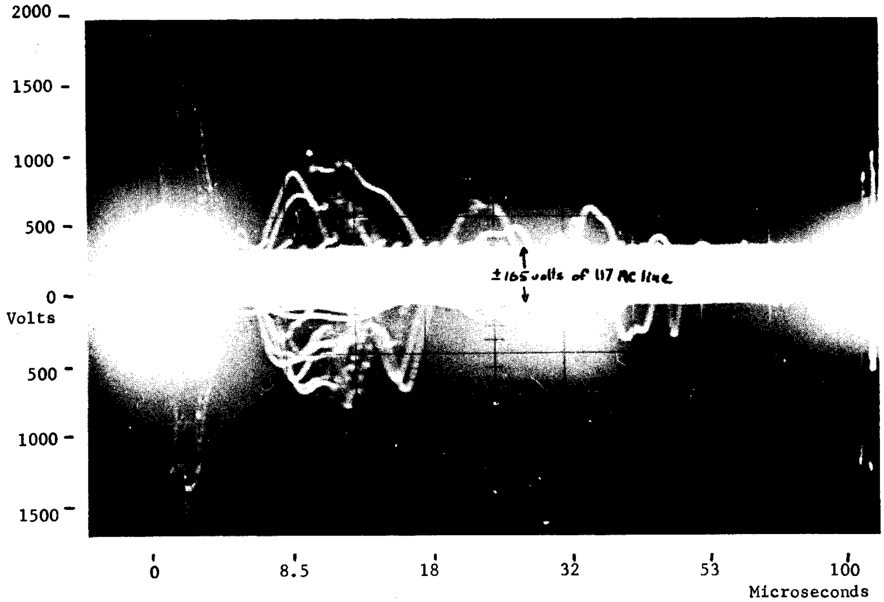
1. Two-terminal Asymmetrical and Symmetrical Silicon Negative Resistance Switches, Journal of Applied Physics, Vol. 30 #11, November 1959, Pg. 1819 - 1824.

2. TIS 62GL191 - Transient Overvoltages in Low Voltage Systems and Their Effect on Solid State Products.

ACKNOWLEDGMENT

The author wishes to acknowledge the contributions of J. D. Harnden, Jr., in establishing the program of this test series and in the presentation of the test results.

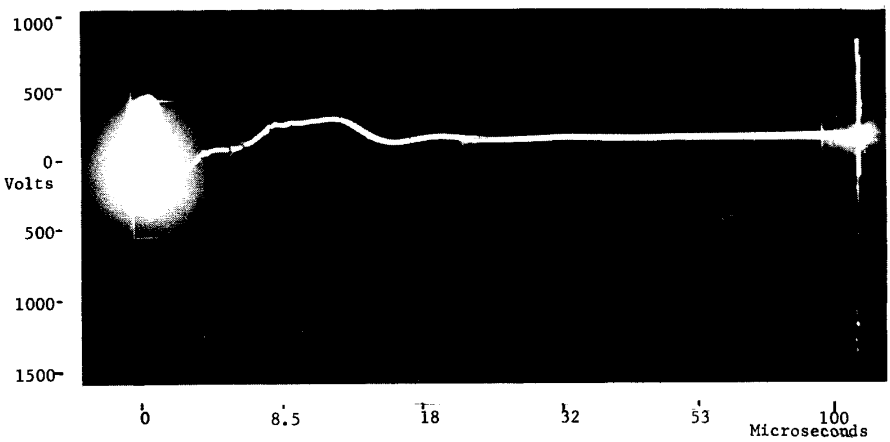
Typical Surges Recorded at
Mr. W.H. Bellamy's House - Stewart Manor, L.I., N.Y.
Feb. 16-Feb. 21, 1963



Composite record showing surges for a 24-hour period.

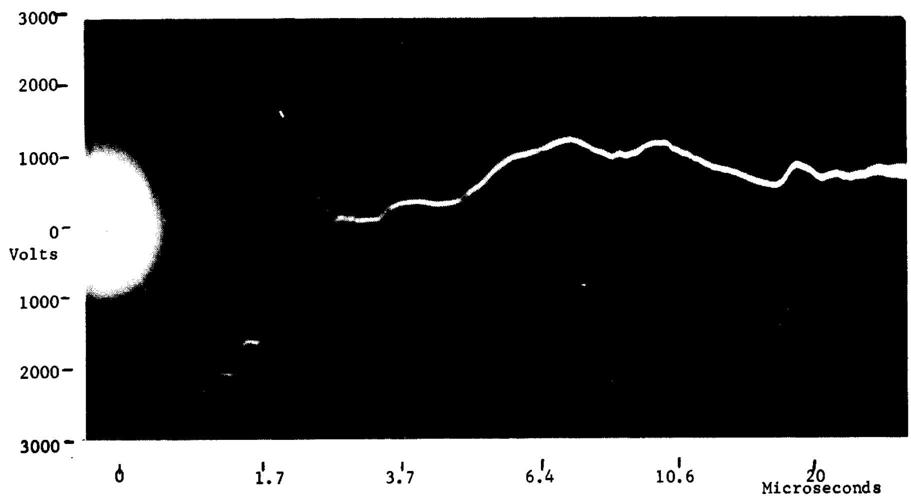
Oscilloscope is triggered for each surge, plus once every hour, resulting in ± 165 volt band of steady-state 60 cps voltage.

Recordings above 1800V are blanked out by oscilloscope.



Single surge occurring 150 μs after initial, low amplitude surge triggered the oscilloscope.

Cause not determined.



Maximum recorded surge, at 2600 volts.

In a 5-day period surges oi this wave shape were recorded as follows:

Number of surges	Voltage Range
1	2500 - 3000
21	2000 - 2500
18	1500 - 2000
13	1000 - 1500

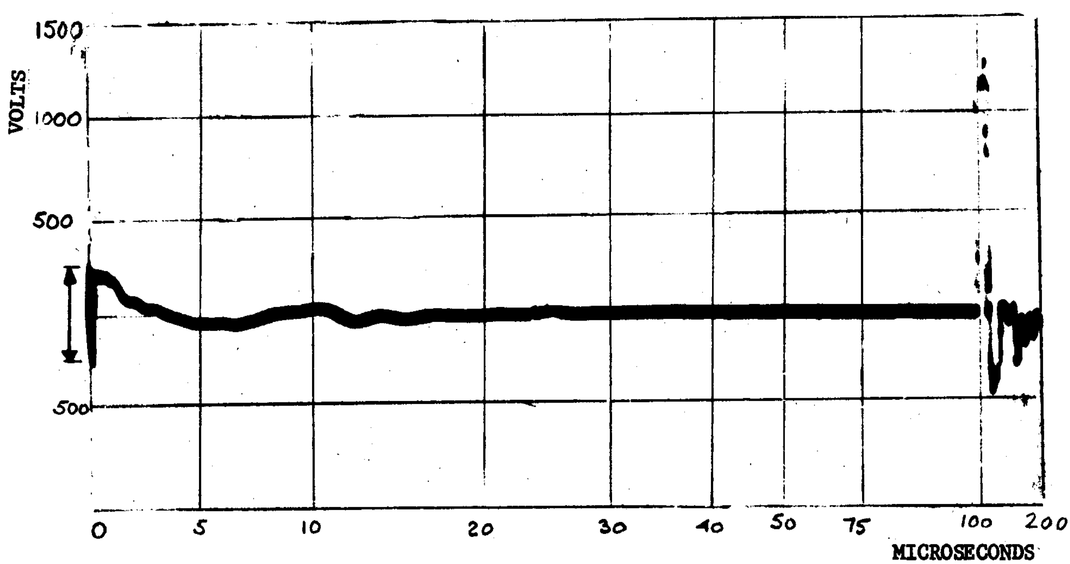
Cause: H.V. transformer foi oil furnace interrup

FIGURE 4

TYPICAL SURGES RECORDED

AT H. R. SELLERS, UTICA, N. Y.

JANUARY 1963



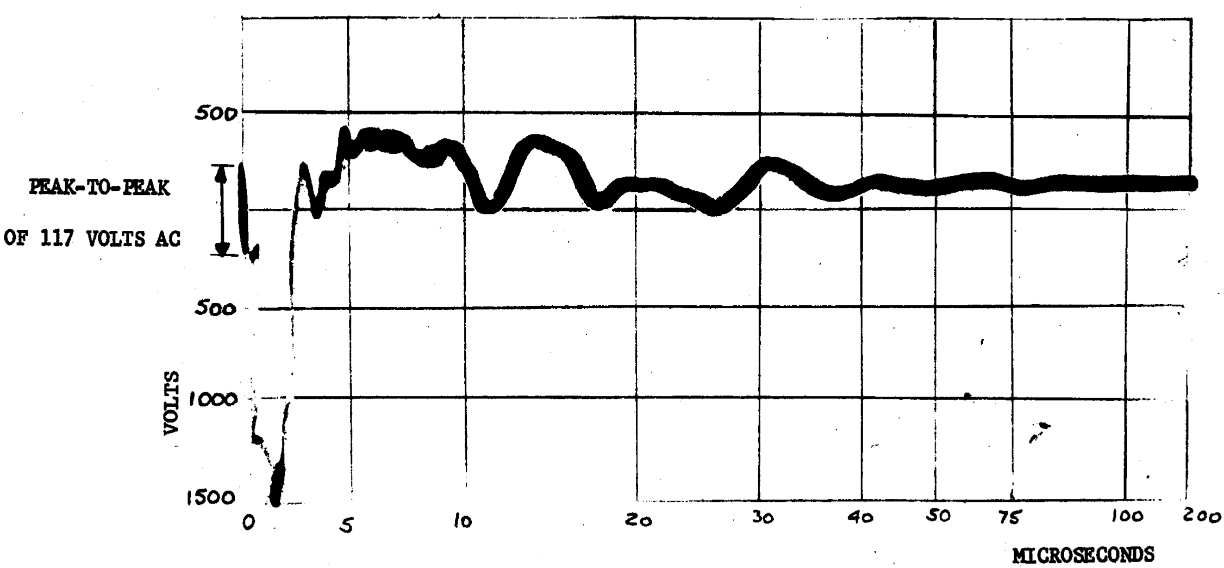


FIGURE 5